

# PROBING THE DARK ENERGY

Huterer-Turner astroph/0012510

CAN'T BOTTLE IT OR  
MAKE IT AT ACCELERATORS

DON'T HAVE A CLUE AS TO ITS NATURE



CHARACTERIZE BY

$$w(t) = \langle p/\rho \rangle_{\text{space}}$$

MST-White  
PKD56, 4439 (97)

GOAL: USE COSMOLOGY TO MEASURE



w AFFECTS EXPANSION HISTORY

$$H(z)^2 = H_0^2 [\Omega_M (1+z)^3 + \Omega_X e^{\int(1+w) d \ln(1+z)}]$$

$(1+z)^3(1+w)$  for const w



3 parameters:  $\Omega_M, \Omega_X, w$   $2, F \Omega_X + \Omega_X = 1 : \Omega_M, w$

$$r(z) = \int \frac{dz}{H(z)} \quad t = \int \frac{dz}{(1+z)H(z)} \quad \ddot{\delta}_k + 2H\dot{\delta}_k - 4\pi G p_m \delta_k = 0$$

& COSMOLOGICAL OBSERVABLES

# THE DARK ENERGY PROBLEM

"DON'T HAVE A CLUE AS TO WHAT THE DARK ENERGY IS!"

"RIGHT NOW, NOT ONLY FOR COSMOLOGY BUT ALSO FOR ELEMENTAL PART. THEORY, THIS IS THE BONE IN OUR THROAT" - S. WEINBERG

IT IS SMOOTH, HAS REPULSIVE GRAVITY, & INVISIBLE FUND PARTS

CHARACTERIZE IT BY  $w_x \equiv P_x/p_x$ ,  $w_x(t)$   
AS A START

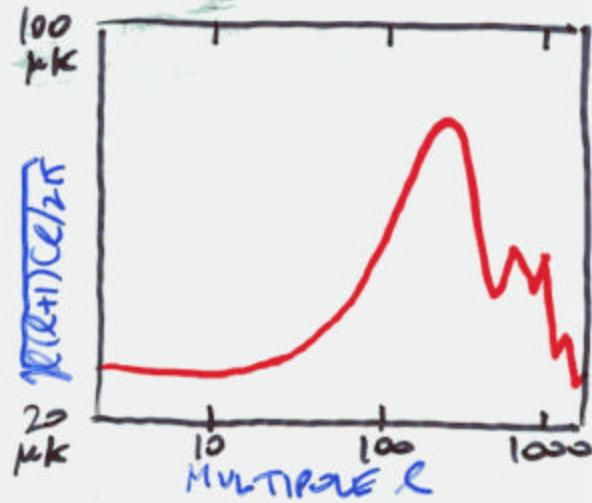
TURNER-WHITE  
PLD 56, 4439 (97)

CANDIDATE	$w$	$w$
COSMOLOGICAL CONSTANT ( $\Lambda$ )	-1	0
FLUSTRATED DEGREES $N=1$ (string), 2 (walls)	$-\frac{N}{3}$	$\approx 0$
FALSE VACUUM STATE	-1	$\approx 0$
ROLLING SCALAR FIELD "QUINTESSENCE"	$-1 \rightarrow 1$	$= \frac{\frac{1}{2}\dot{\phi}^2 - V(\phi)}{\frac{1}{2}\dot{\phi}^2 + V(\phi)}$
"THE BULK", BREAKDOWN OF FLRW COSMOLOGY, ...	?	?

# CMB ANISOTROPY

POSITIONS OF ACOUSTIC  
PEAKS DEPEND UPON  
DISTANCE TO L-S-S:

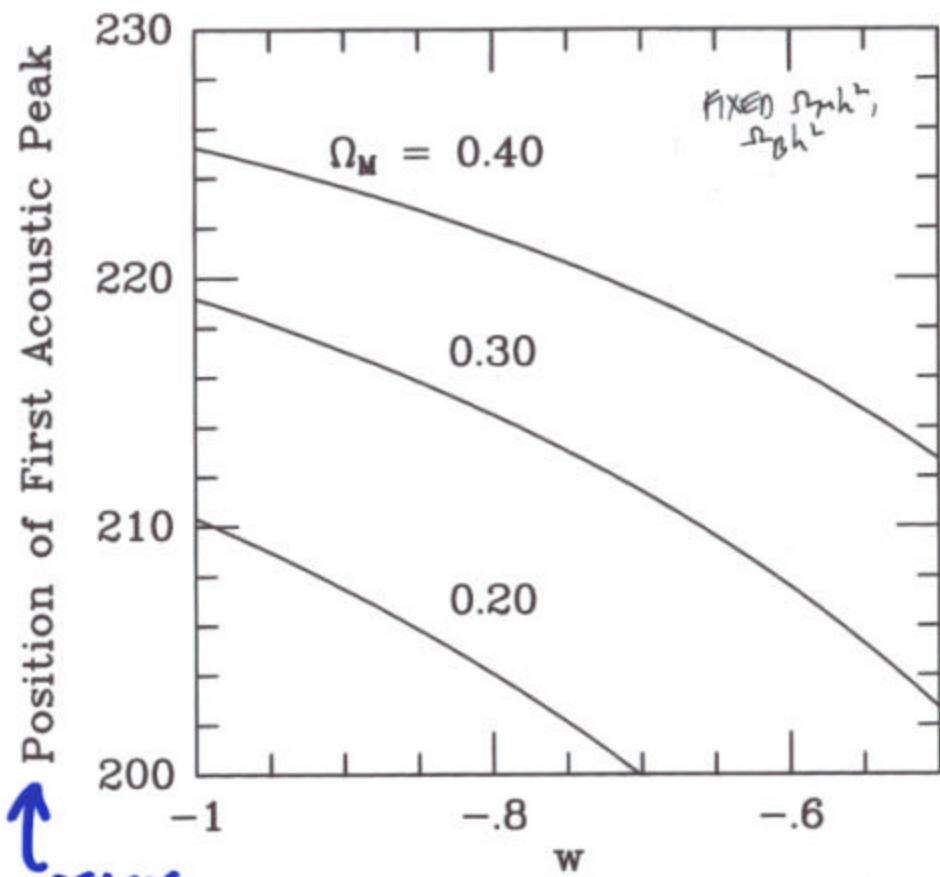
$$r_{LS} = \int_0^{Z \approx 1100} \frac{dz}{H(z)}$$



CAN DETERMINE  $\bar{\omega}$  TO  
 $\pm 0.3$  (PLANCK w/ 10 $\ell$ )

CAN'T ADDRESS TIME  
VARIATION

$Z_{LS} \approx 1100$  FIXED!



PLANK  
 $\sigma_8 \approx 0.3$

↑  
 OTHERS  
 HARMONICALLY  
 RELATED

$$\Delta \ell_1 / \ell_1 \approx -0.084 \Delta w$$

$$-1.25 \frac{\Delta \Omega_M}{\Omega_M} + 0.09 \frac{\Delta \Omega_M}{\Omega_M} + 0.09 \frac{\Delta \Omega_B h^2}{\Omega_B h^2} - 0.23 \frac{\Delta \Omega_B h^2}{\Omega_B h^2}$$

# TYPE IA SUPERNOVAE

BASELINE: 2020 SNe,  $z \approx 0.2 - 1.7$   $\Delta m = 0.15$

MEASURE  $m(z)$ , DETERMINE  $r(z)$

$$r(z) = \frac{d_L(z)}{(1+z)} = \frac{1}{(1+z)} \left[ \frac{1}{5} (m - M) - 5 \right]^{exp 10}$$

• DETERMINE  $w$  TO  $\pm 0.05$

• PROBE  $w(z)$

E.G.  $w(z) = w(z_1) + w'(z - z_1)$   $z_1 \approx 0.3$

$$\sigma_{w(z_1)} = 0.02 \quad \sigma_{w'} = 0.16 \quad [\text{FIXED } \Delta m]$$

• "RECONSTRUCT"  $w(z)$  OR  $V(\phi)$

$$1+w(z) = \frac{1+z}{3} \frac{3H_0^2 \Omega_m (1+z)^2 + 2r''/r'^3}{H_0^2 \Omega_m (1+z)^3 - 1/r'^2} \quad \text{NOT FOR THE FAIR THREADED!}$$

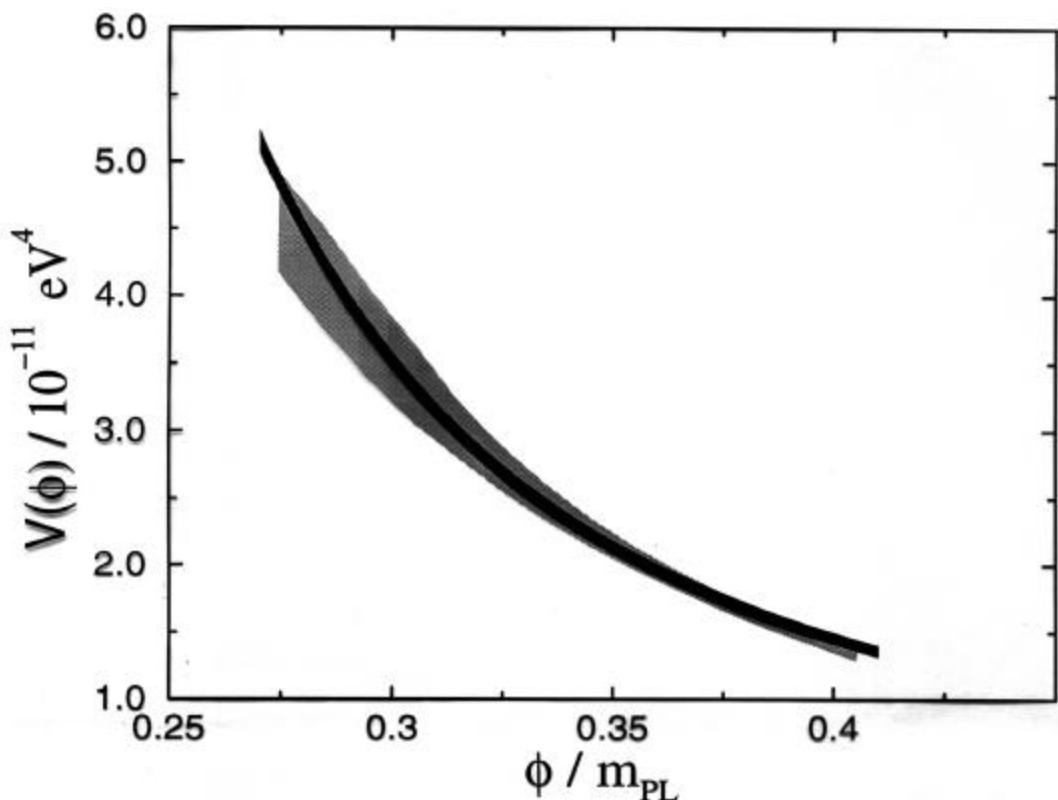
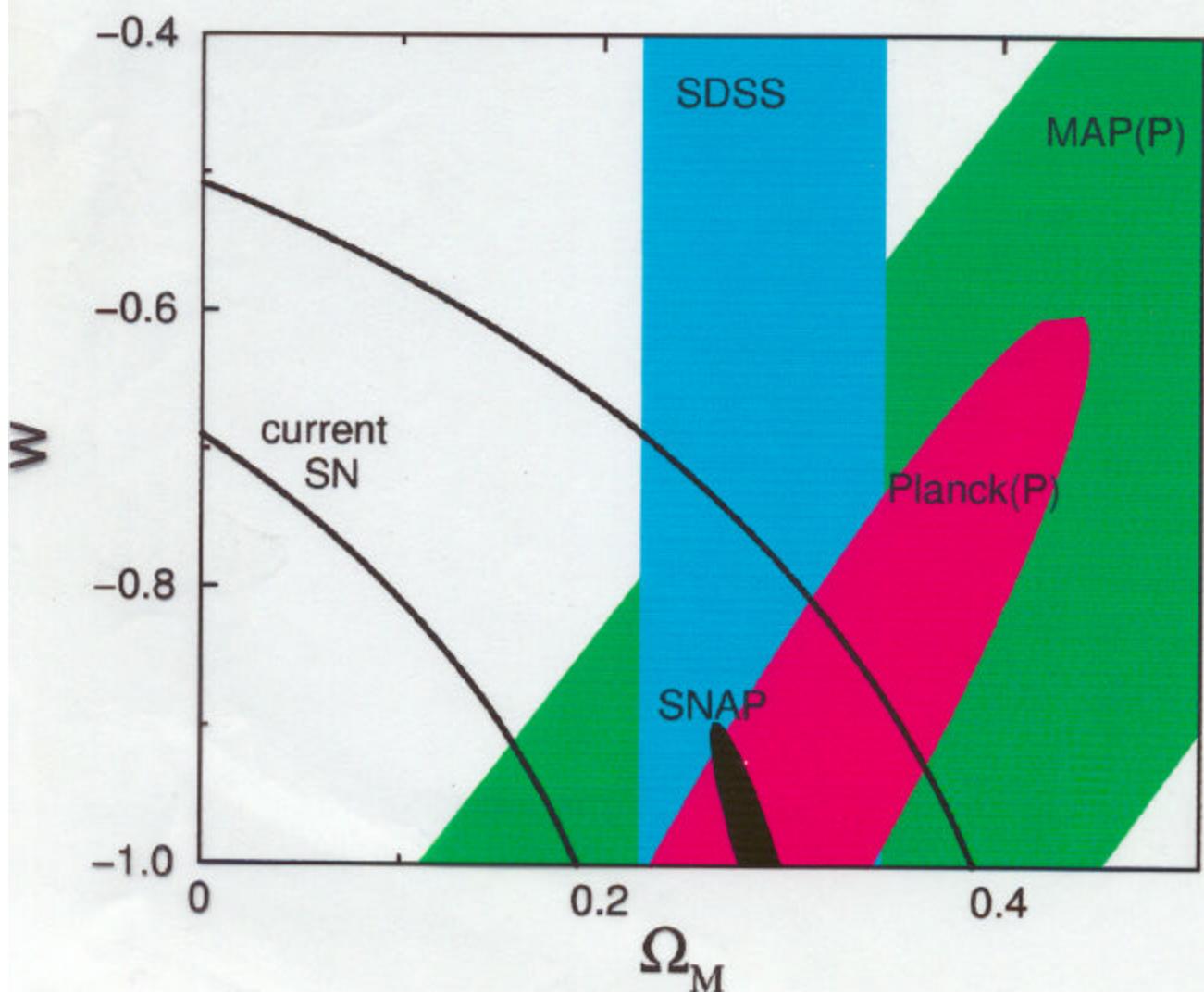
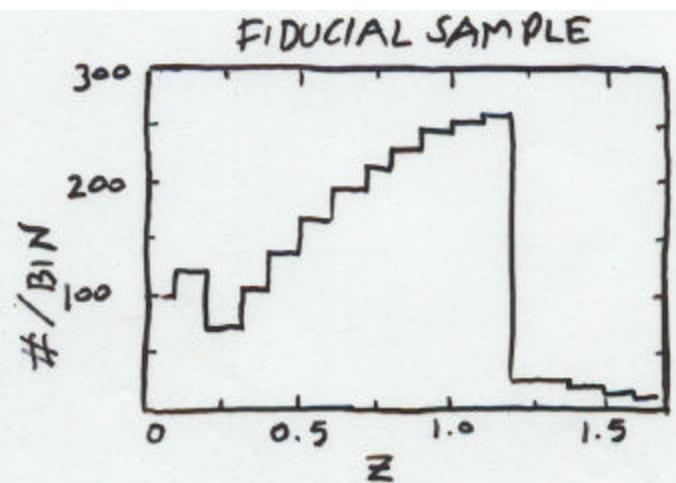


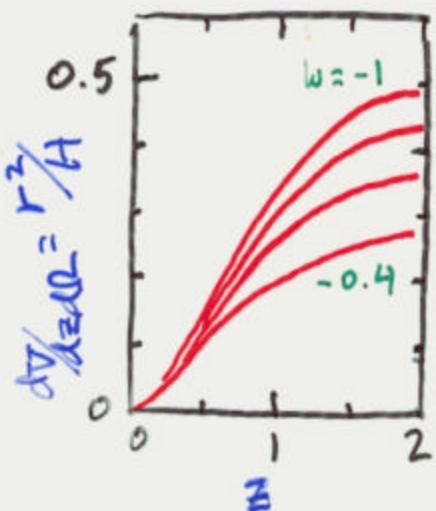
Figure 1: The 68% confidence interval for the reconstructed potential assuming SNAP's data set (shaded area) and the original potential (heavy line). The quintessence potential is  $V = V_0 [\exp(m_{PL}/\phi) - 1]$  with  $V_0 = 1.3 \times 10^{-12}$  (eV) $^4$  and  $\Omega_{dark} = 0.52$ . The simulated distance-redshift data were fit by a three-parameter Padé approximant. Note that, for the reconstruction, no *a priori* knowledge about the potential is needed.



# CLUSTER, GALAXY COUNTS

$$\frac{dN}{dz d\Omega} = \frac{dV}{dz d\Omega} * n(z)$$

↑  
MEASURE



$n(z)$

DETERMINE FROM SIMULATIONS

## HALOS OF FIXED MASS

Davis-Newman ApJ 513, L95(99)

$z \approx 0.7-1.5$   
10,000

$$\sigma_w \approx 0.06 \longrightarrow 0.2$$

Poisson

10% error in  
 $n(z)$

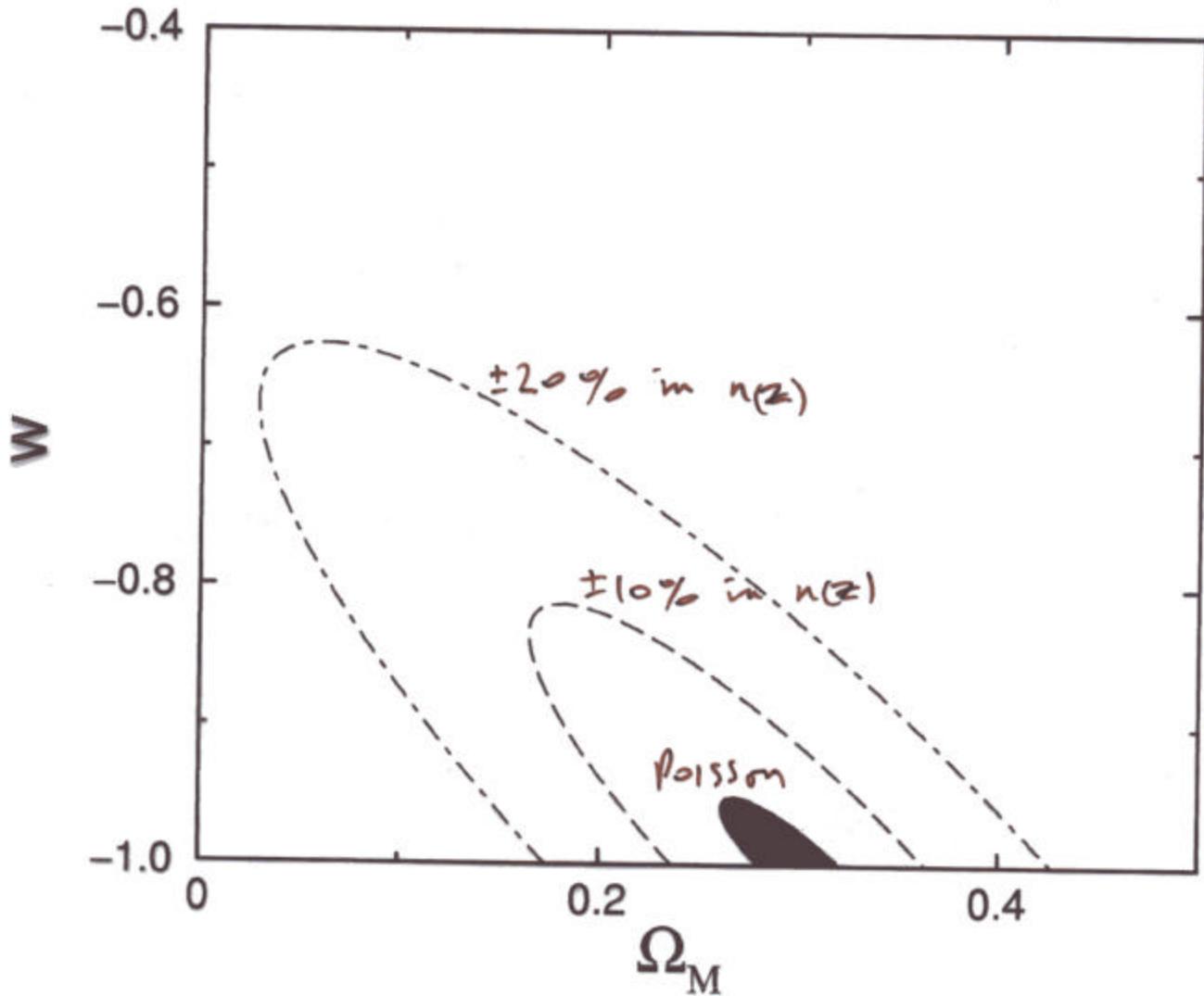
CLUSTERS From X-RAY SZ SURVEY  
 $z=0-3$

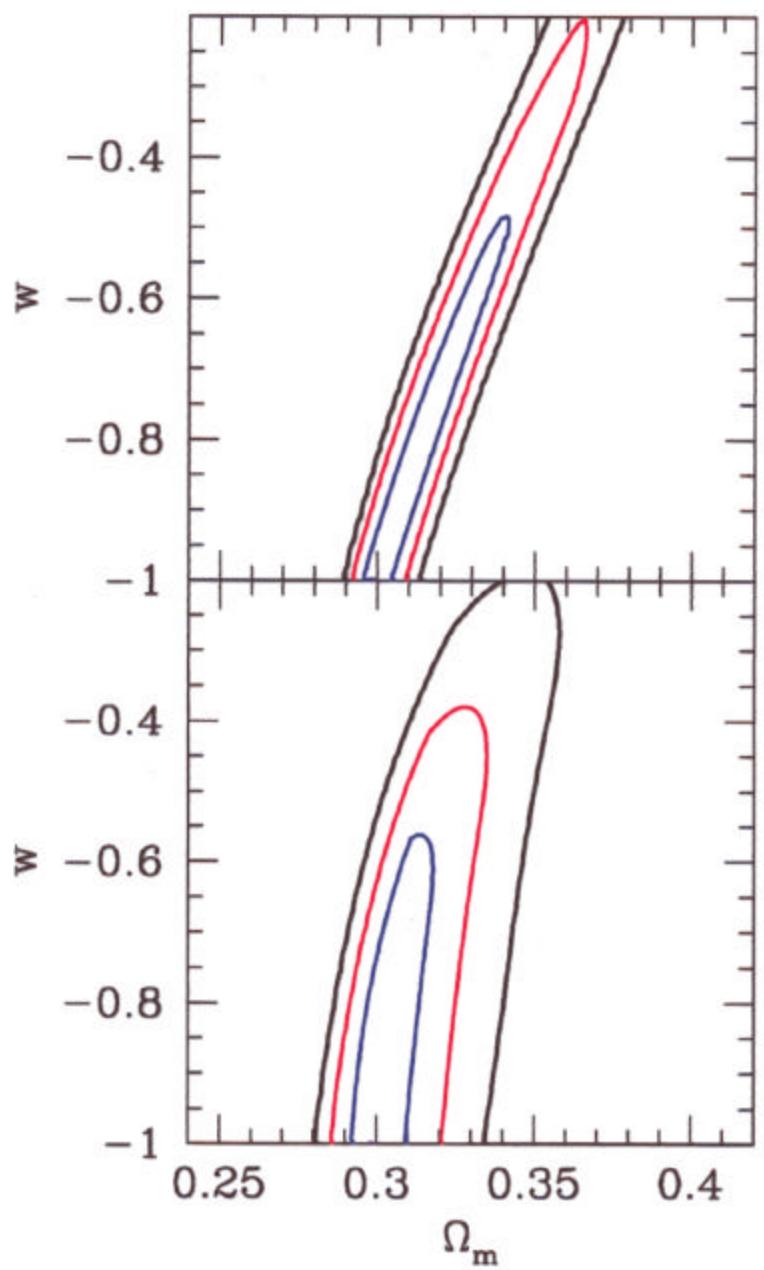
Holder et al astro-ph/0002336 V3

$$\sigma_w \approx 0.4 \text{ (S-Z)}, 0.5 \text{ (X-ray)}$$

# HALO COUNTS w/ DEEP

Davis - Newman ApJ 513, L95 (99)





CONTOURS  
1, 2, 3 $\sigma$

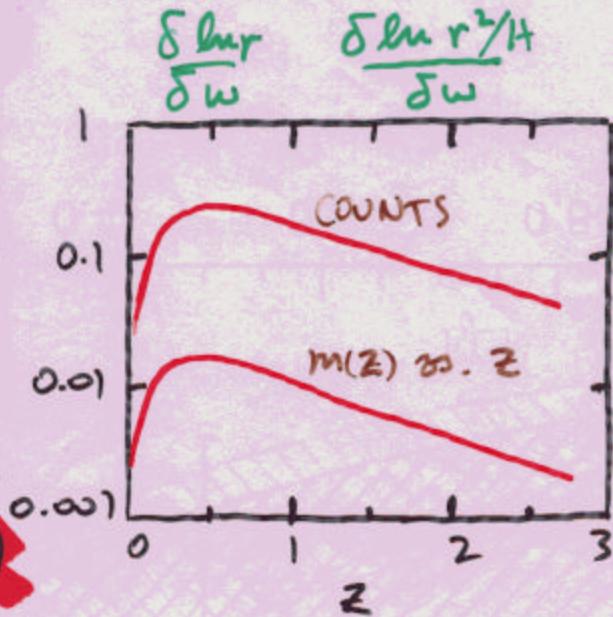
Holder et al  
astro-ph/0002336

# OPTIMAL STRATEGIES

REDSHIFT  
SENSITIVITY  
TO  $w$

$z \approx 0.2 - 2$

sweet spot = 0.4



LOSE SENSITIVITY AT

$z > 0$

$r(z) \rightarrow 1+z$  INDEPENDENT OF  $w$

$z \gg 1$

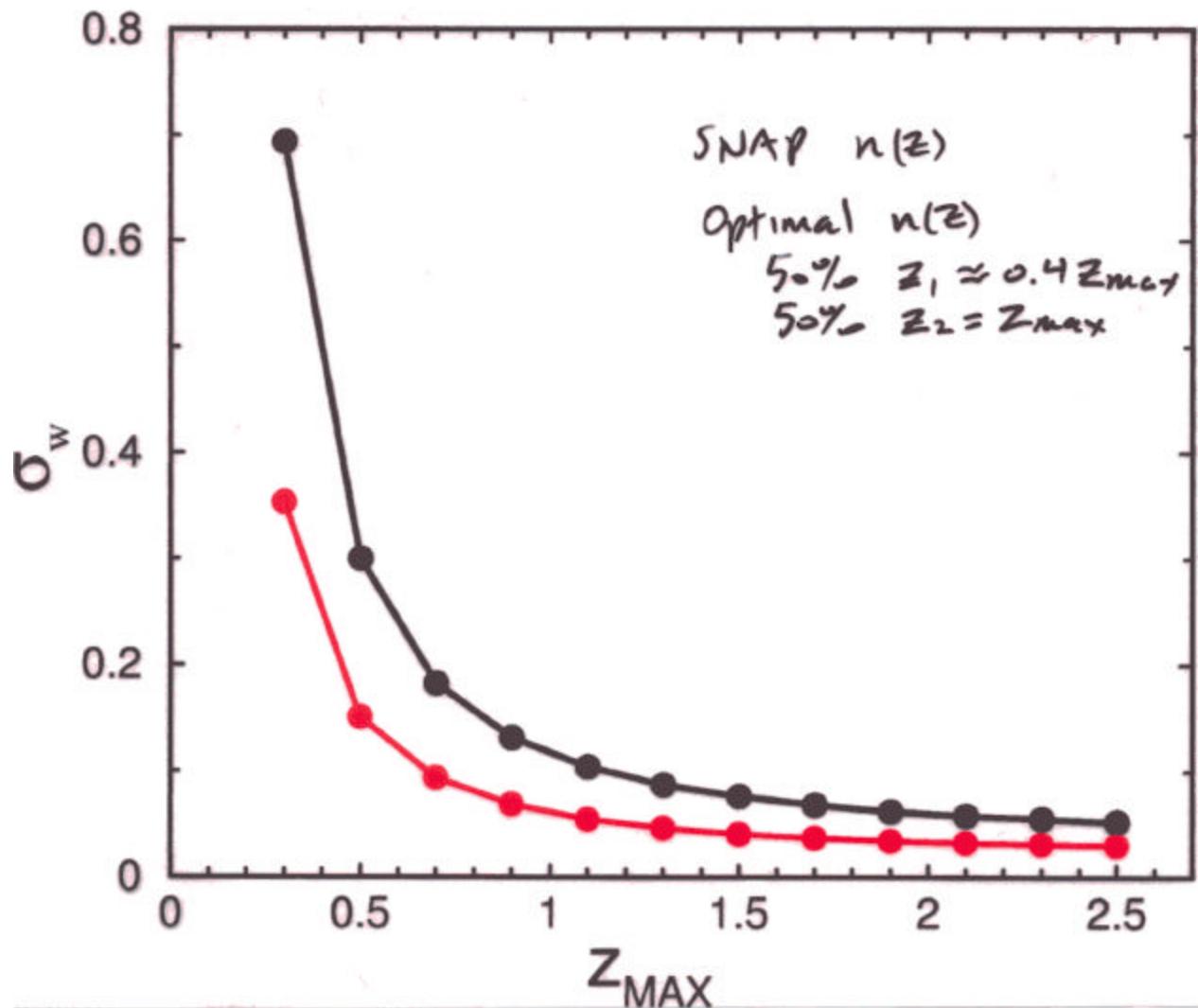
$\rho_x/\rho_m \rightarrow (1+z)^{3w} \rightarrow 0$   
DARK ENERGY  
NOT IMPORTANT

COSMOLOGICAL DATA

AT  $z \approx 0.2 - 2$

MOST EFFECTIVE

UNLESS  $\rho_x/\rho_m \rightarrow$   
CONSTANT  $\pm \ln z^{-n}$



# COSMOLOGICAL OBSERVATIONS ARE KEY TO SOLVING DARK ENERGY RIDDLE

SNeIa

$\Omega_W \approx 0.05$ , RECONSTRUCTION

... ARE THEY STDIZABLE CANDLES

Galaxies, Clusters

$\Omega_W \approx 0.05$

... EVOLUTION OF  $n(z)$

Structure Evolution thru  
grav lensing ?

NEEDS TO BE STUDIED

CMB, Alcock-Paczynski, Hoto : confirming evidence, less probative